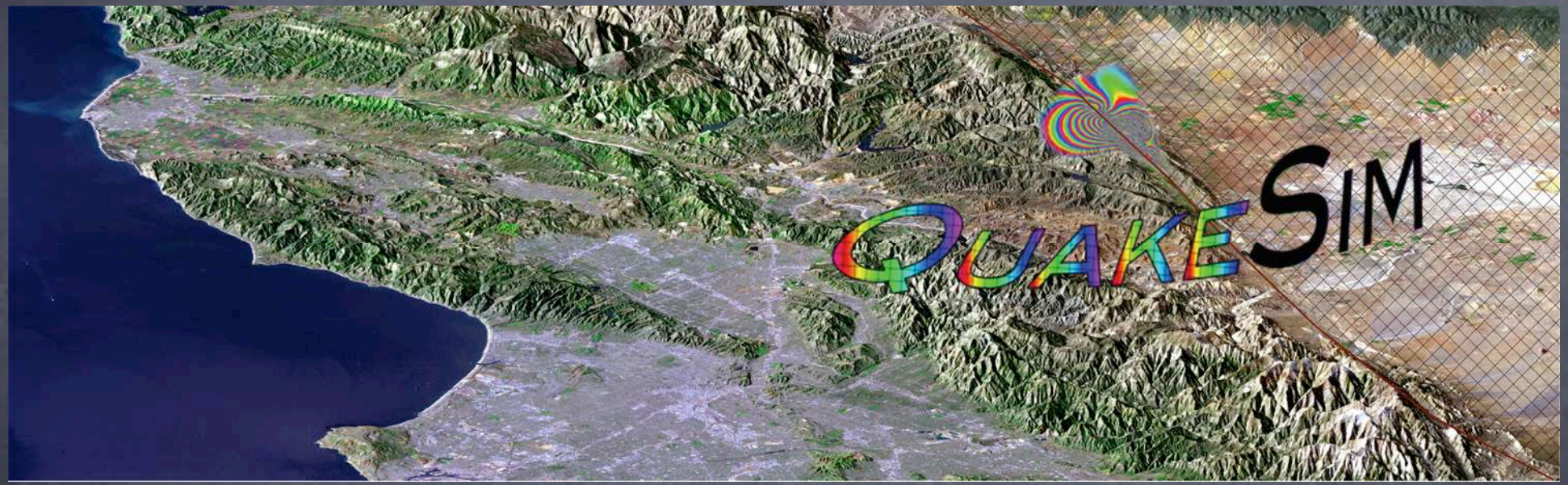
Developing Parallel GeoFEST(P) Using the Pyramid AMR Library



Charles D. Norton, Greg Lyzenga, Jay Parker, and E. Robert Tisdale
Jet Propulsion Laboratory
California Institute of Technology

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Quakesim/GeoFEST(P) Project Contributors

Andrea Donnellan

Principal Investigator

Jay Parker, Greg Lyzenga, and Teresa Baker

GeoFest Geophysical Finite Element Simulation Tool

Charles Norton and Bob Tisdale

PYRAMID Parallel Unstructured Adaptive Mesh Refinement Library

Peggy Li

RIVA Visualization

Cinzia Zuffada

Validation

Michele Judd

Task Management

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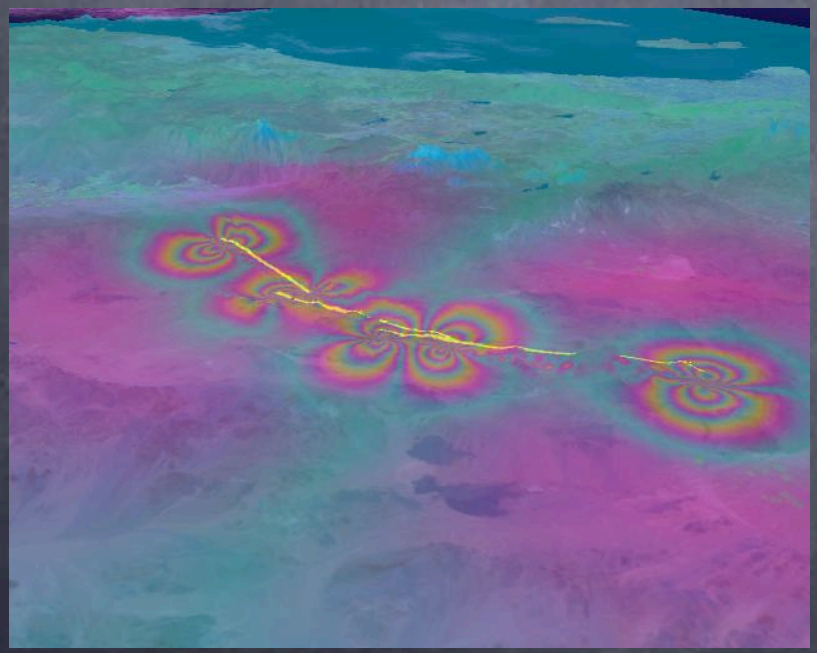
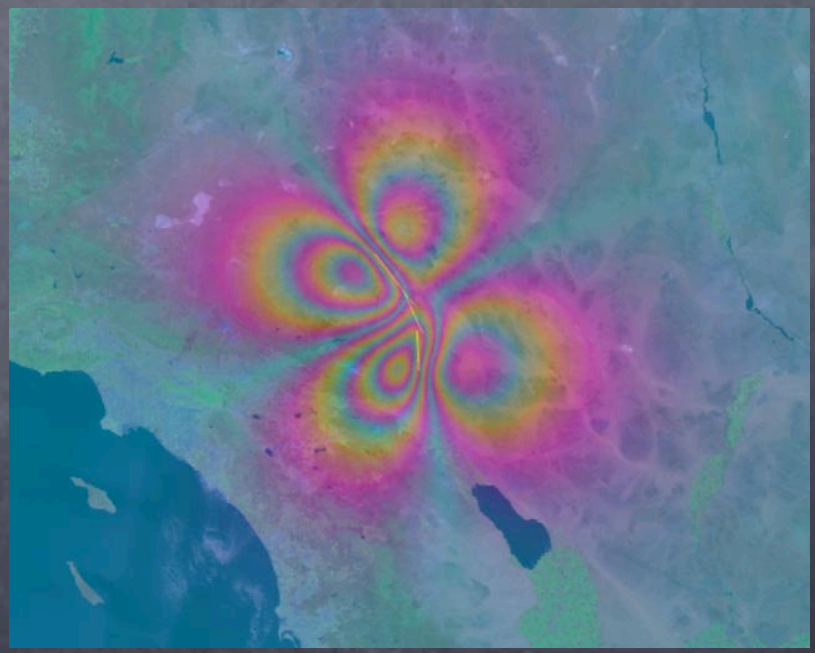
Description of GeoFEST(P)

Parallel finite element software package for modeling solid stress and strain in geophysical and other continuum domain applications

Coseismic vertical deformation

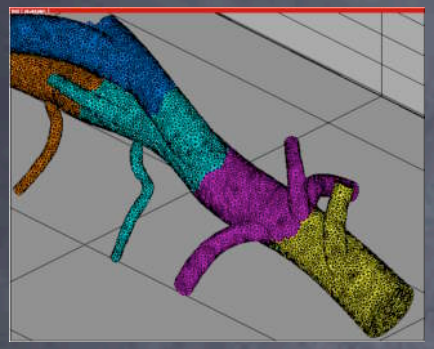
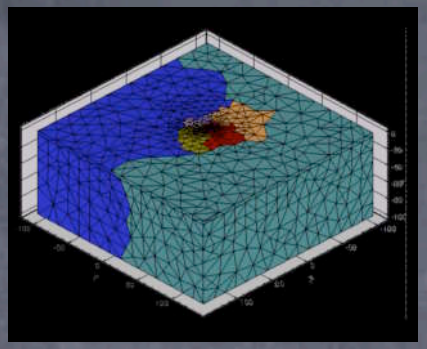
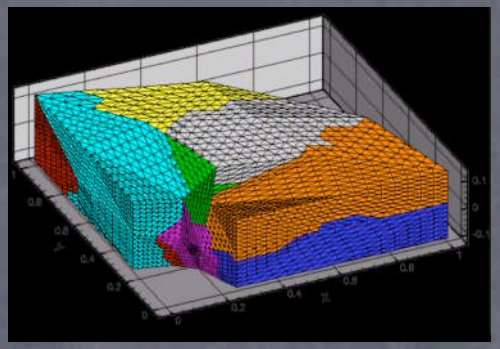
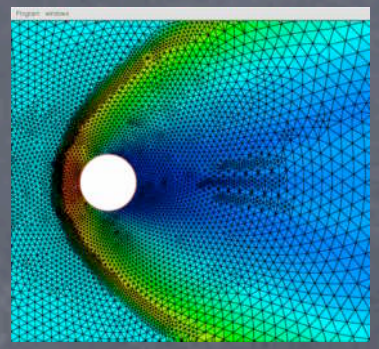


Postseismic elastic relaxation at 500 years



Simulation visualizations showing In-Sar fringes of surface uplift from Landers earthquake fault event
Instantaneous event (left) and post-seismic surface uplift after 500 simulation years (right)

Description of Pyramid

Task Objective

Development of an advanced software library supporting parallel unstructured adaptive mesh refinement for large-scale scientific and engineering modeling applications

Design Approach

Efficient object-oriented design in Fortran 95 with MPI

Automatic mesh quality control, dynamic load balancing, mesh migration, partitioning, integrated mathematics, data accessibility routines, easy solver integration

Scalable to hundreds of processors and millions of elements using triangles (2D) and tetrahedra (3D)

Power, completeness, and ease of use

NASA and ESTO/CT Relevance

Large-scale modeling and simulation applications with complex geometry including support for ESTO/CT Round III teams for Solid Earth modeling and more

Relevant Application Areas

Structural modeling and engineering mechanics for Earth and space science applications

Fluid mechanics and gas dynamics

Solid Earth active tectonics simulation models

Electromagnetics

NASA

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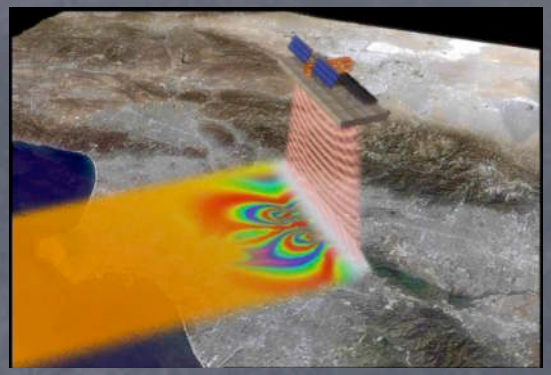
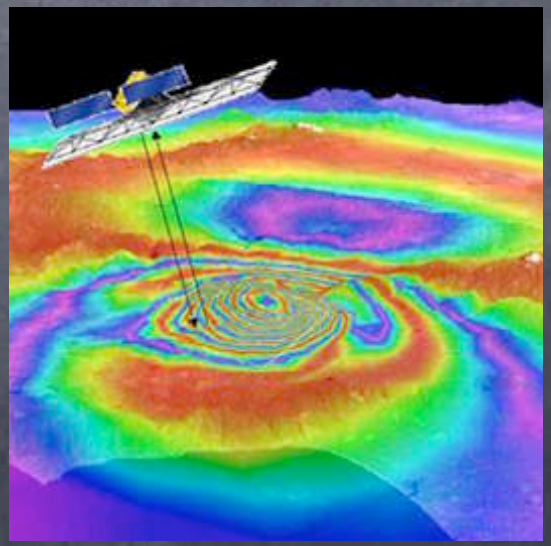
Why Parallelize GeoFEST?

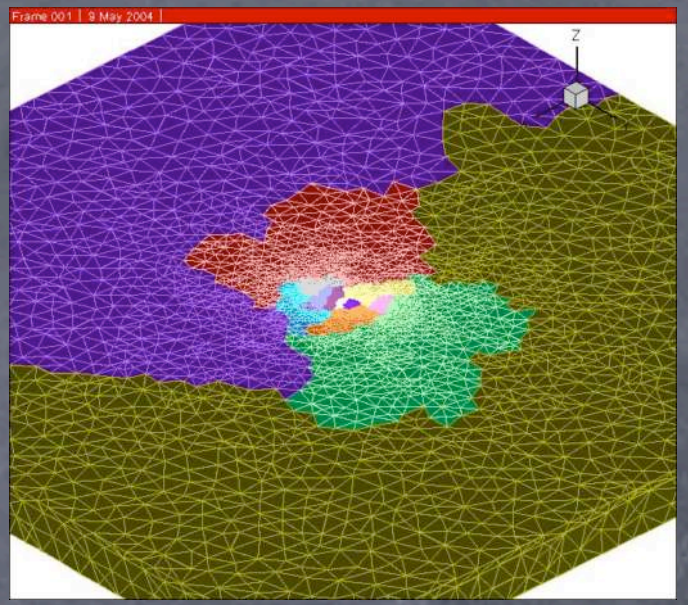
- Simulates and produces synthetic observable time-dependent surface deformations on scales from days to decades
- Aids in interpretation of GPS, InSAR, and other geodetic techniques from exponentially increasing data volumes from NASA remote sensing programs

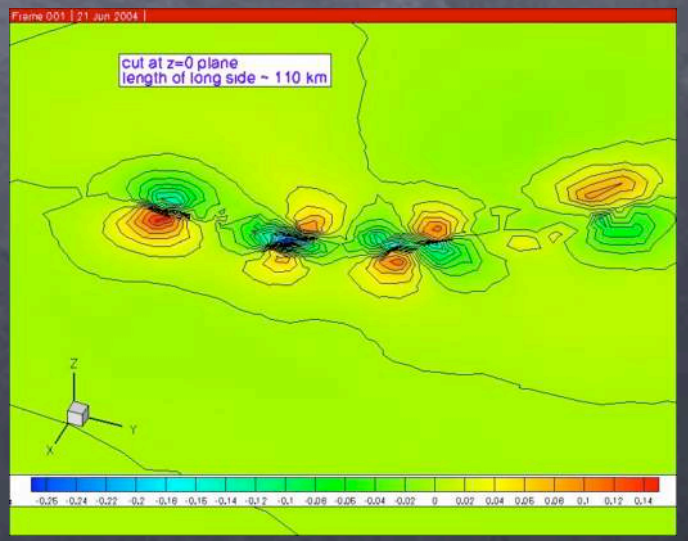




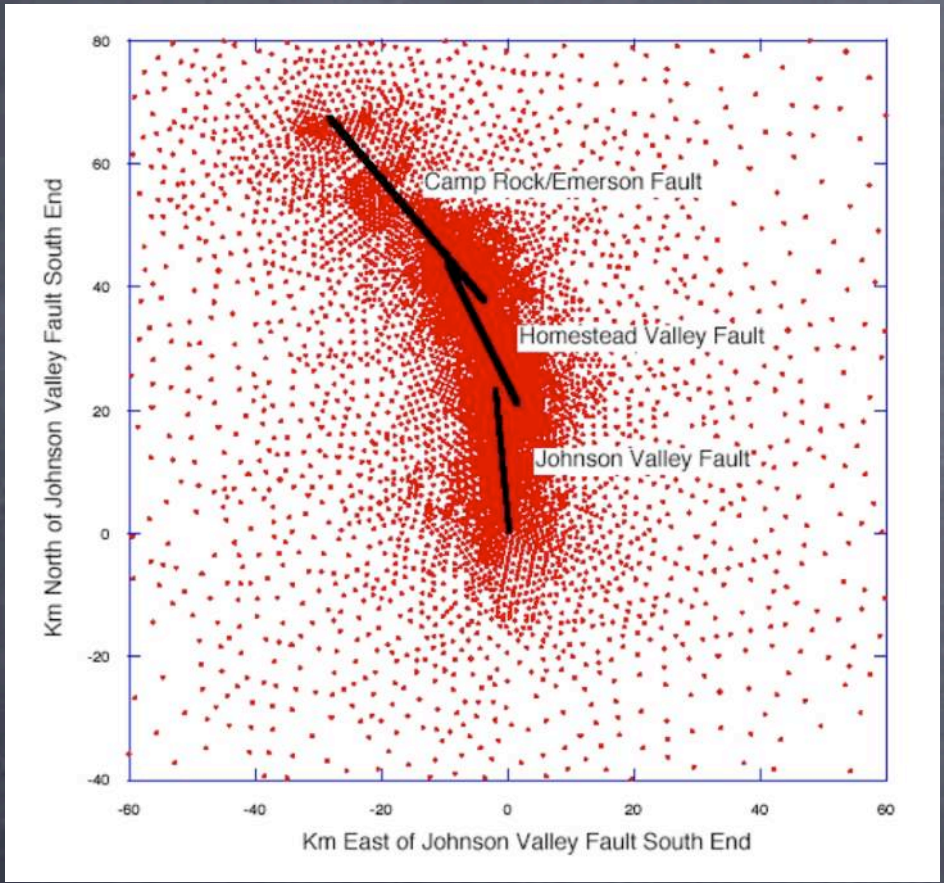
Major Accomplishments of GeoFEST(P)

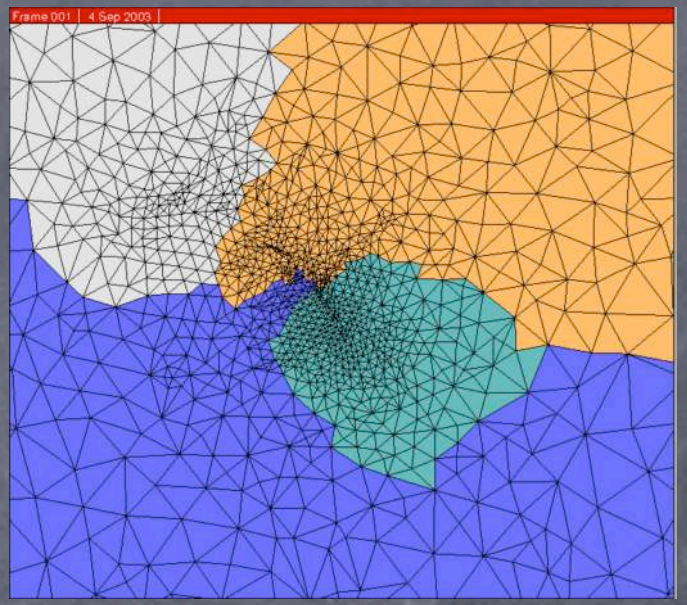
- Geophysical Finite Element Simulation Tool
- 25x resolution and 4x speedup over baseline case
- Near 98% scaled efficiency across numerous platforms
- Simulations with millions of finite elements supported
- Solver driven mesh adaptation tests look promising

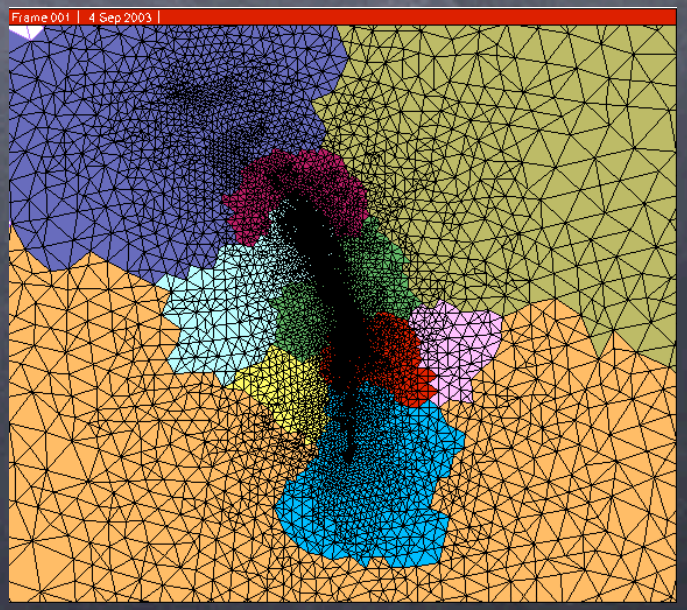




Model of Landers Event with Partitionings

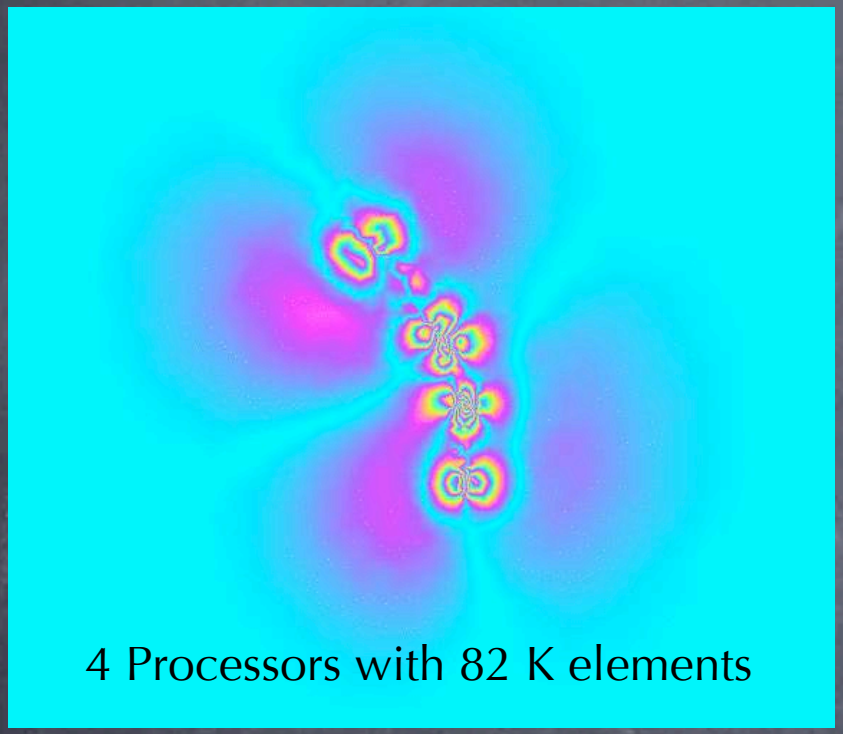




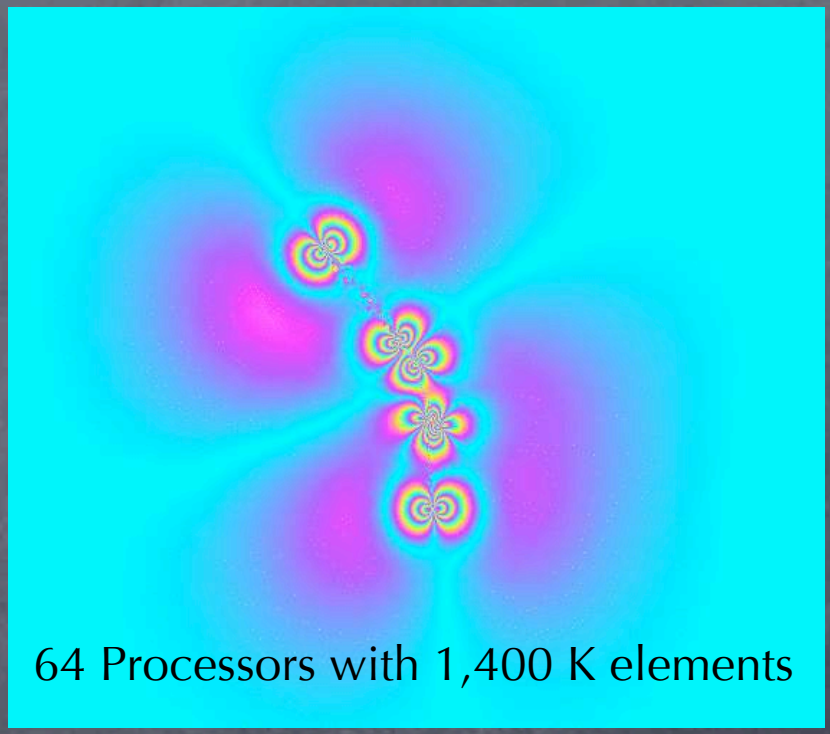


- 82K element partitioning on 4 PEs and 1,400K element partitioning on 16 PEs

Accuracy Improvement with Resolution



4 Processors with 82 K elements



64 Processors with 1,400 K elements

- More elements, enabled by parallelism, improves resolution of InSar fringes

Development Highlights

- Interoperable code in C and Fortran 95
- Element-based balanced domain partitioning with MPI for inter-processor communication
- Approximately 160 references to Pyramid (~30 unique) from 9526 lines of GeoFEST or ~1.7%
- Approximately 4 months development time with 2 months of optimization
- Available at OpenChannelFoundation.org

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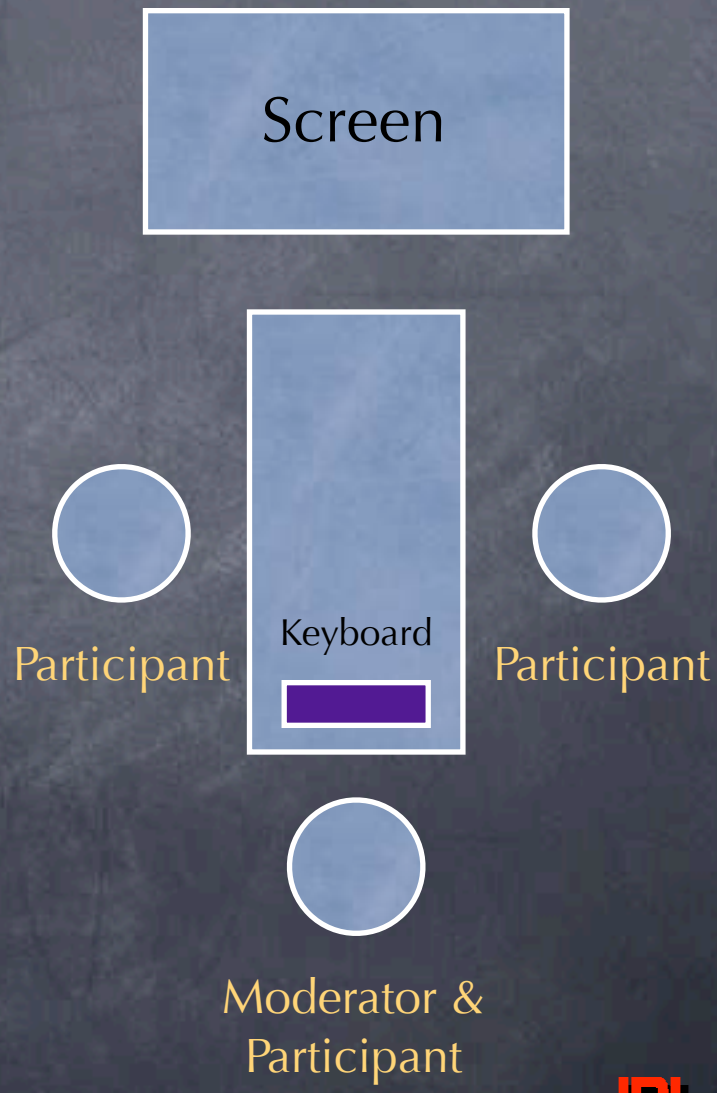
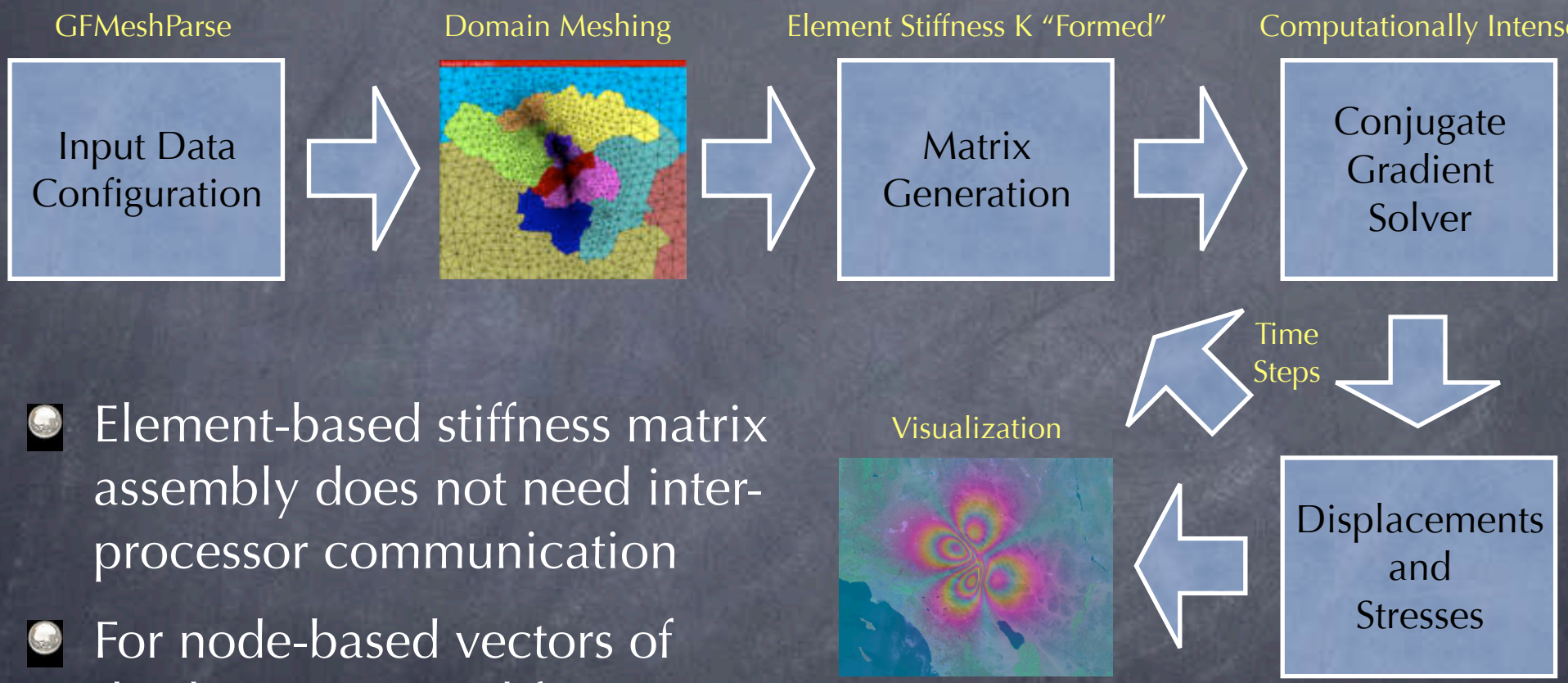
"Extreme" Software Development

- Interactive and collective software development
- Allows pooling of expertise and minimizes software errors
- Not an a-priori objective, but was effective for coupling these codes
- Bounding number of participants is important



Computational Flow



- Element-based stiffness matrix assembly does not need inter-processor communication
- For node-based vectors of displacements and forces we must account for redundant data on shared boundaries

Efficient message passing methods address this issue

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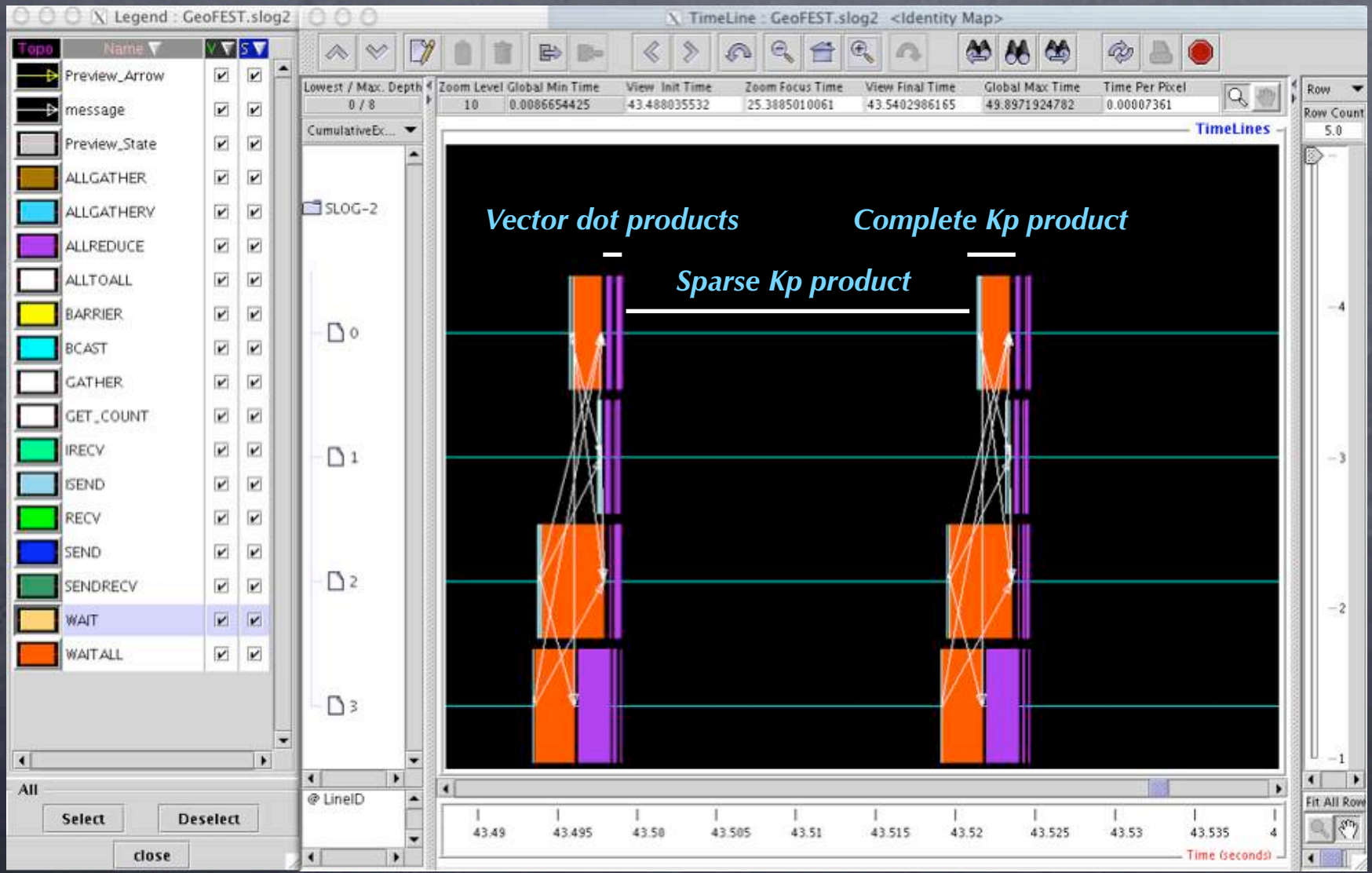
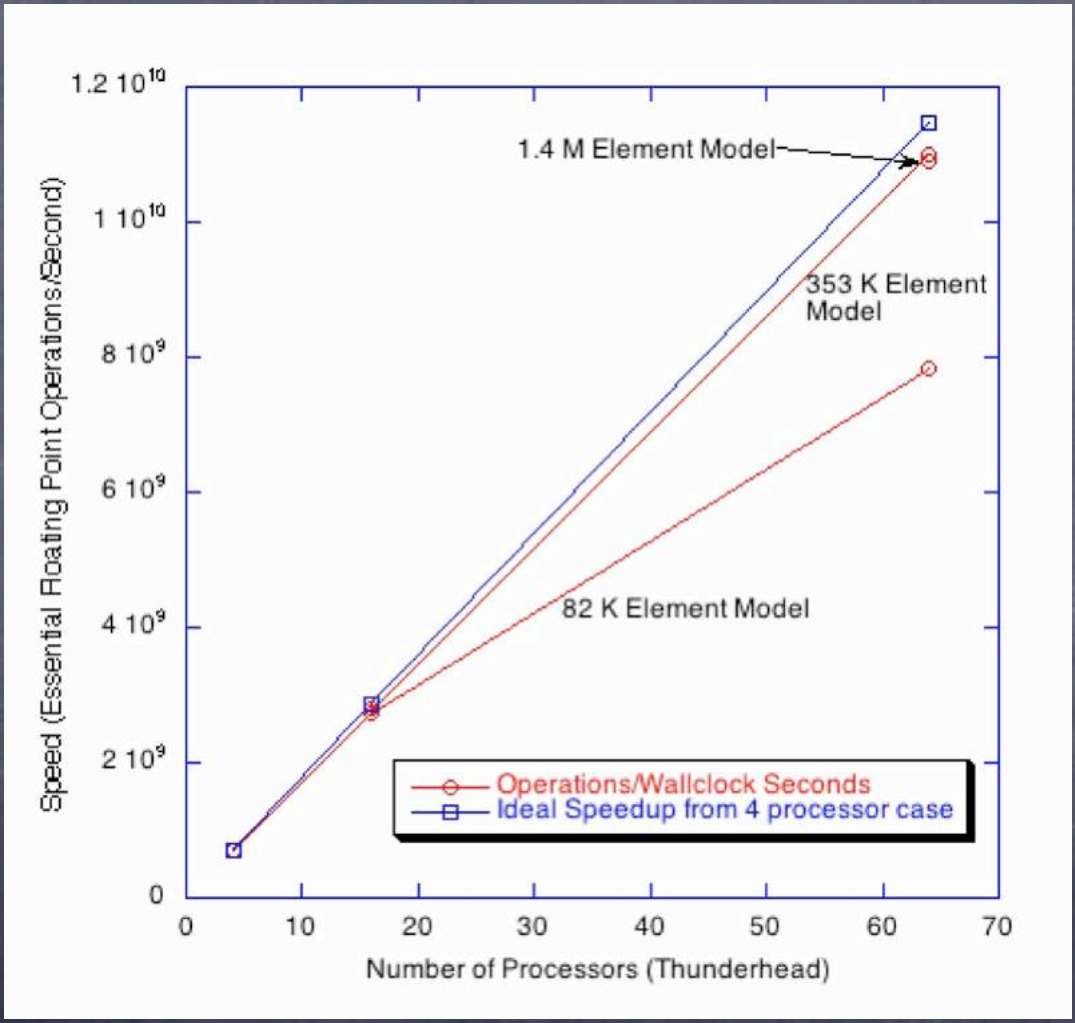
Performance Characterization



Two iterations of PCG solve of the thousands from simulation runs

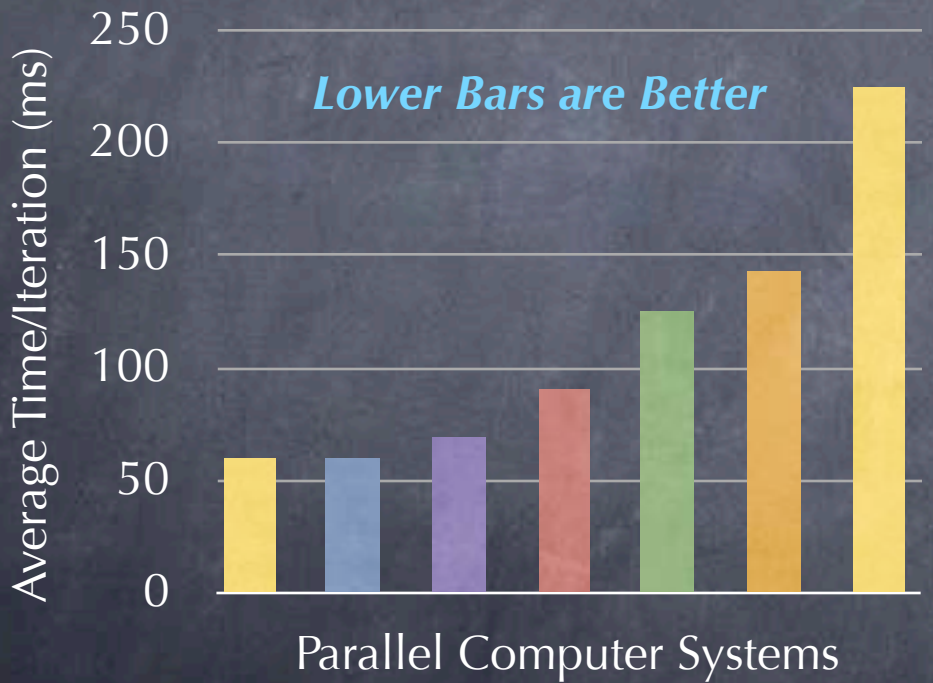
Performance Characterization



Scaling for Landers Case on Scaled Problem Sizes

Performance Characterization

Average time per iteration for parallel solve used as comparative benchmark among platforms



- Apple 2.0 GHz PPC G5 970 (Infiniband)
- Intel 3.0 GHz Pentium IV (GigE)
- Intel 2.4 GHz Pentium Xeon (Myrinet)
- SGI 1.5 GHz Altix 3000 (NUMA-Link)
- HP 1.0 GHz Itanium 2 (QsNET)
- SGI 0.9 GHz Altix 3000 (NUMA-Link)
- Apple 1.0 GHz PPC G4 (GigE)

Avg. Time/iteration is "constant" for arbitrary number of processors

Solve is computation bound, but scheme efficiently handles communication of data on irregular mesh partition boundaries over multiple iterations per time-step

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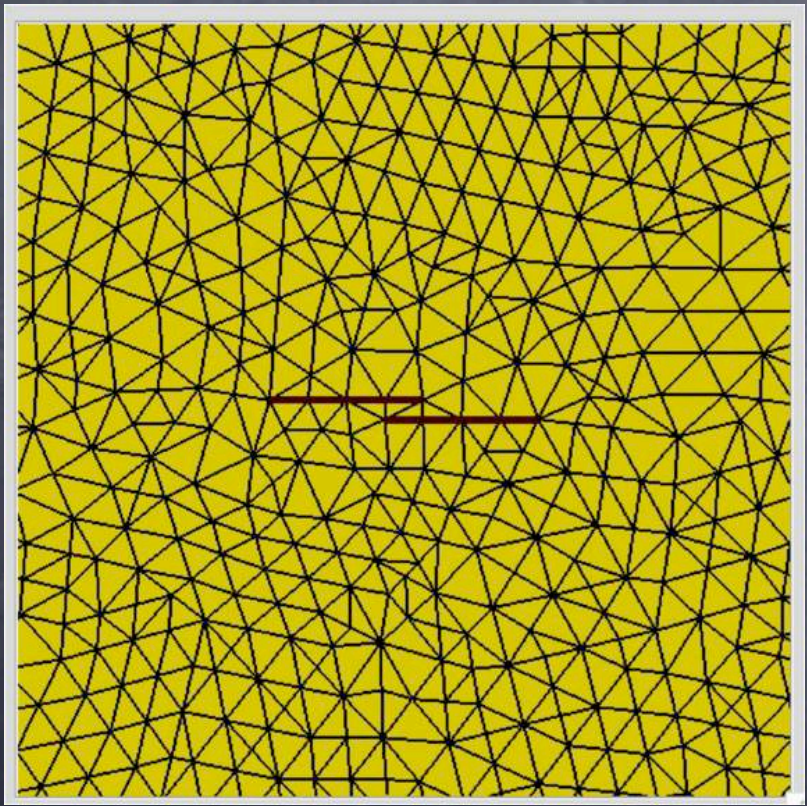
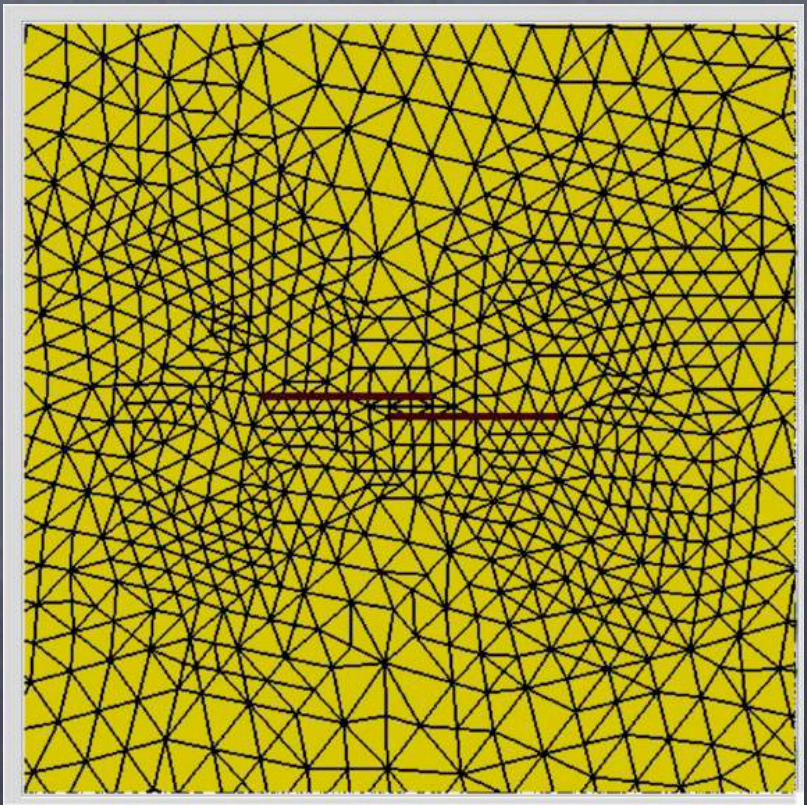
Early Fault Stepover AMR Results

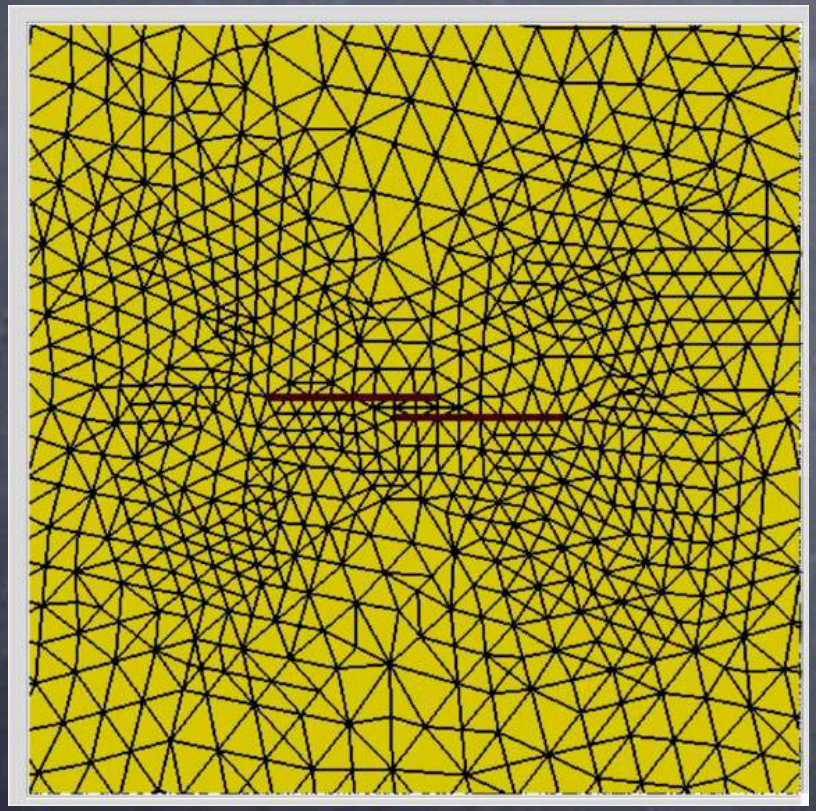
Initial and refined mesh (sequential) based on strain energy where fault stepover is seen as dark bars

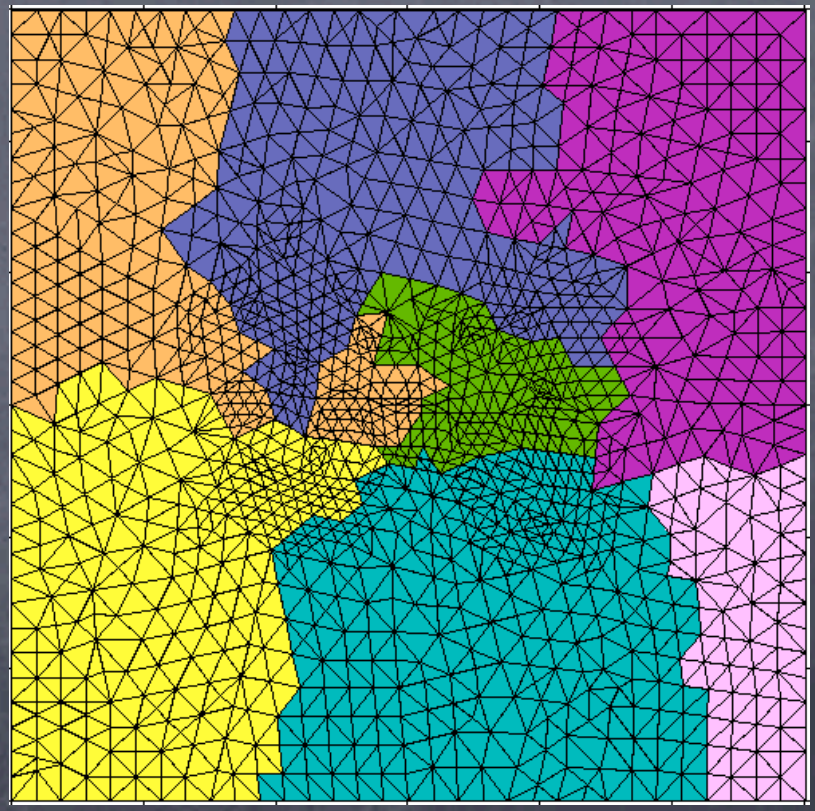




Early Fault Stepover AMR Results

Error Estimation Driven AMR (parallel) based on strain-energy for fault stepover using Pyramid in GeoFEST(P)





Actual domain is 3D - only surface is shown

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More Information

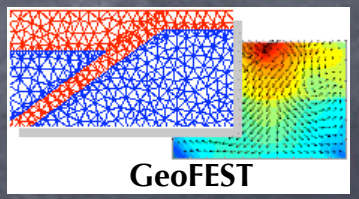
NASA ESTO/CT Project

http://ct.gsfc.nasa.gov/

ESTO/CT QuakeSim Project at JPL

http://quakesim.jpl.nasa.gov/

GeoFEST and PYRAMID Software



http://www.openchannelfoundation.org/projects/GeoFEST

http://www.openchannelfoundation.org/projects/pyramid

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